SYSTEM AND METHOD FOR EVALUATING ACCURACY OF AN AUTOMATIC LOCATION IDENTIFICATION SYSTEM

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TECHNICAL FIELD OF THE INVENTION

[0001]   The present invention relates to the field of wireless communication networks. More specifically, the present invention relates to evaluating the accuracy of automatic location identification systems used to locate wireless communication devices originating emergency calls.

BACKGROUND OF THE INVENTION

[0002]   Today's society is highly mobile. That is, individuals can move rapidly from one location to the next by utilizing automobiles, mass transit, bicycles, and the like. The advantages of communication any time and almost anywhere, advances in technology, and the affordability of wireless communication devices, such as cell phones, pagers, personal communications systems (PCS), and personal digital assistants (PDA) have resulted in a proliferation of these wireless communication devices in this mobile society.

[0003]   Concurrent with the proliferation of wireless communication devices is the increased frequency of emergency calls originated from the wireless communication devices. These emergency calls are also referred to herein as 911 calls, representing the emergency services number "911" utilized in the United States. The ability to place 911 calls from wireless devices has contributed greatly to improving public safety, and is an important resource for individuals who need help desperately, but could not previously communicate that need. Unfortunately, many mobile callers dialing 911 to report an emergency do not know exactly where they are. This lack of

spatial consciousness means operators at public safety
answering points (PSAPs) may not be able determine a caller's
location so that emergency response personnel can be quickly
and accurately dispatched to the appropriate location.

[0004]   In 1996, the Federal Communications Commission
(FCC) issued a Report and Order requiring all wireless carriers
and cell phone manufacturers to provide the capability for
automatically identifying to emergency dispatchers the location
from which a wireless call is being made. The FCC's wireless
911 mandate seeks to both improve the reliability of wireless
911 services and to provide enhanced features generally
available for wireline calls.

[0005]   Timing for implementing the 911 call requirements
is divided into two phases. Phase I requires wireless carriers
to deliver to the emergency dispatcher the telephone number of
a wireless handset originating a 911 call, as well as the
location of the cell site or base station receiving the 911
call, which provides a rough indication of the caller's
location. This phase was implemented by the end of 1998.
Phase II requires carriers to deliver more specific latitude
and longitude location information, known as Automatic Location
Identification (ALI), to the dispatcher in response to a 911
call initiated by a wireless device.

[0006]   Various location determination technologies (LDT)
are being developed to locate wireless communication devices in
response to the FCC 911 Phase II mandate. These technologies
encompass both network-based and handset-based equipment and
processes. Broadly defined, a network-based technology is one
in which the wireless communication network detects the signal
transmitted from a wireless communication device and uses that
signal to determine the current location of the wireless

device. A hand-set based technology is one in which the
wireless communication device detects signals transmitted from
multiple base stations and/or satellites and uses those signals
to determine the current location of the wireless device. In
addition, hybrid techniques make use of both network-based and
handset-based technologies to produce a more robust estimate of
current location in a single process.

[0007]   The FCC has adopted accuracy and reliability
requirements for ALI as part of the Phase II mandate. The
rules for network-based technologies specify accuracy and
reliability requirements of one hundred meters for sixty-seven
percent of emergency calls and three hundred meters for ninety-
five percent of emergency calls. The rules for handset-based
technologies specify accuracy and reliability requirements of
fifty meters for sixty-seven percent of emergency calls and one
hundred and fifty meters for ninety-five percent of emergency
calls.

[0008]   The deployment of an ALI system, and in
particular, one used to provide 911 call Phase II compliant
services, needs to be validated with a comprehensive test of
all the environments that exist in thousands of service areas,
each covering hundreds of square miles, to determine whether
the ALI system complies with the accuracy standards set by the
FCC. The FCC further recommends a biannual post-deployment
validation of the accuracy of the ALI system. Unfortunately, a
comprehensive validation of an ALI system using current
empirical observations is both costly and time consuming, and
requires a wireless carrier to hire a large staff of both
highly skilled and medium to low skilled personnel.
Furthermore, a comprehensive validation of an ALI system calls

for a large number of repetitive tasks and significant human intervention, which increases the probability of error.

SUMMARY OF THE INVENTION

[0009]   Accordingly, it is an advantage of the present invention that a method and system are provided for evaluating the accuracy of an automatic location identification system (ALI).

[0010]   It is another advantage of the present invention that the method and system evaluate an ALI system based on FCC accuracy and reliability requirements.

[0011]   It is another advantage of the present invention that the method and system minimize error and costs by effectively utilizing automated tools for repetitive tasks.

[0012]   Another advantage of the present invention is that the method and system enable completion of comprehensive validations in a timely manner with minimum need for specialized staff.

[0013]   Yet another advantage of the present invention is that the method and system are operable independent from the particular ALI technology deployed.

[0014]   The above and other advantages of the present invention are carried out in one form by a method for evaluating accuracy of an automatic location identification (ALI) system configured to locate a wireless communication device originating an emergency call through a wireless communication network. The method calls for identifying a validation region in which a service area of a public safety answering point (PSAP) and a radio frequency (RF) coverage area of the wireless communication network overlap. A test scenario is selected that represents a calling environment in which the

emergency call may occur, and a test point is chosen in the
validation region exhibiting the calling environment
represented by the test scenario. The method further calls for
determining a ground truth of the test point and performing a
test call from the test point, the test call simulating the
emergency call. A reported location of the test point is
obtained from the ALI system in response to the performing
operation, and the reported location is compared with the
ground truth to determine the accuracy of the ALI system in
response to predetermined accuracy parameters.

   [0015]   The above and other advantages of the present
invention are carried out in another form by a computing system
for selecting test points in a validation region. The test
points are used to validate accuracy of an automatic location
identification (ALI) system operating in the validation region,
and the ALI system is configured to locate a wireless
communication device originating an emergency call through a
wireless communication network. The computing system includes
a processor, a computer-readable storage medium, and executable
code recorded on the computer-readable storage medium for
instructing the processor to select the test points. The
executable code includes a validation region map subprocess for
forming a validation region map of the validation region. The
validation region map represents an overlap of a service area
of a public safety answering point (PSAP) and a radio frequency
(RF) coverage area of the wireless communication network. The
executable code further includes a sub-region classification
subprocess for partitioning the validation region map into a
plurality of sub-regions and correlating each of the sub-
regions with one of a plurality of test scenarios, each of the
test scenarios representing a unique calling environment in

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which the emergency call may occur. A test point selection
subprocess of the executable code chooses the test points in
response to a selected one of the test scenarios, the test
points exhibiting the unique calling environment represented by
the selected one of the test scenarios.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016]   A more complete understanding of the present
invention may be derived by referring to the detailed
description and claims when considered in connection with the
Figures, wherein like reference numbers refer to similar items
throughout the Figures, and:

[0017]   FIG. 1 shows a simplified diagram of an
environment in which an emergency call, originated from a
wireless communication device through a wireless communication
network, may take place;

[0018]   FIG. 2 shows a flow chart of an automatic
location identification (ALI) evaluation process in accordance
with the present invention;

[0019]   FIG. 3 shows a block diagram of a computing
system through which the ALI evaluation process of FIG. 2 is
executed;

[0020]   FIG. 4 shows a flow chart of a validation region
identification subprocess of the ALI evaluation process of FIG.
2;

[0021]   FIG. 5 shows a diagram of a service area map of a
public safety answering point (PSAP);

[0022]   FIG. 6 shows a diagram of a wireless service area
map of the wireless communication network approximately
corresponding to the PSAP service area map of FIG. 5;

[0023]   FIG. 7 shows a diagram of a radio frequency (RF) coverage area map of the wireless communication network;

[0024]   FIG. 8 shows a diagram of an overlay map that represents the PSAP service area of FIG. 5 overlaying the radio frequency (RF) coverage area of FIG. 7;

[0025]   FIG. 9 shows a diagram of a validation region map compiled through the execution of the validation region identification subprocess of FIG. 4;

[0026]   FIG. 10 shows a flow chart of a sub-region classification subprocess of the ALI evaluation process of FIG. 2;

[0027]   FIG. 11 shows a table of a partial listing of a test scenario database that includes exemplary test scenarios in which the performance of an automatic location identification system 36 deployed in the environment of FIG. 1 may be evaluated;

[0028]   FIG. 12 shows a diagram of a populated validation region map;

[0029]   FIG. 13 shows a table of a partial listing of a sub-region classification database that includes sub-regions within the populated validation region map of FIG. 12 correlated with the test scenarios of FIG. 11;

[0030]   FIG. 14 shows a flow chart of a test point selection subprocess of the ALI evaluation process of FIG. 2;

[0031]   FIG. 15 shows a flow chart of an empirical test call execution subprocess of the ALI evaluation process of FIG. 2;

[0032]   FIG. 16 shows an diagram of a call record database that includes a plurality of call records produced through the execution of empirical test call execution subprocess of FIG. 15;

[0033]   FIG. 17 shows a flow chart of a predictive test call execution subprocess of the ALI evaluation process of FIG. 2; and

[0034]   FIG. 18 shows a diagram of a simulated environment formed through the implementation of the predictive test call execution subprocess of FIG. 17.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0035]   FIG. 1 shows a simplified diagram of an environment 20 in which an emergency call 22, originated from a wireless communication device 24 through a wireless communication network 26, may take place. Environment 20 represents a geographical region that may include a number of geographical and man-made features. Geographical features include, for example, hilly terrain, heavy foliage, mountains, flat land, water, and so forth. Man-made features include, for example, buildings, roads, bridges, and so forth. In the United States, emergency call 22 may be originated by dialing "911" from either a wireline telephone (not shown) or wireless communication device 24. However, emergency call 22 is not limited to the "911" digits utilized in the United States, but may encompass any digits utilized as an emergency services number in other regions or countries.

[0036]   Wireless communication device 24 engages in wireless communication through one of base stations 28 of wireless communication network 26 by techniques known to those skilled in the art. Per convention, when wireless device 24 participates in a wireless phone call, such as emergency call 22, a channel connection is established between wireless communication device 24 and one of base stations 28 through a call center, such as a mobile telephone switching office (MTSO)

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30.   MTSO 30 then enables connection of emergency call 22 to a
public safety answering point (PSAP) 32 via the public switched
telephone network (PSTN) 34.

[0037]   An automatic location identification (ALI)
system, generally represented by a block 36, is deployed within
environment 20 to locate wireless device 24 initiating
emergency call 22.   ALI system 36 may be a network-based
technology, a handset-based technology, or a hybrid technology.
The current location of wireless communication device 24,
ascertained using ALI system 36, may be reported to PSAP 32.

[0038]   A network-based technology may employ time
difference of arrival (TDOA), angle of arrival (AOA), and/or
location fingerprinting.   TDOA calculates the current location
of a wireless device based on the time at which the radio
frequency signal reaches three or more nearby antennas usually
co-located with base stations 28.   AOA determines the direction
of arrival of an RF communication signal emitted from wireless
device 24.   The phase difference of the RF communication signal
on elements of a calibrated antenna array, usually co-located
with base stations 28, provides a line of bearing to wireless
communication device 24.   The intersection of the lines of
bearing of two or more antenna arrays establishes the current
location.   Location fingerprinting utilizes the distinct RF
patterns (multipath phase and amplitude characteristics) of RF
communication signals arriving at a receiver antenna from a
single caller.   The unique characteristics of the signal are
analyzed and a "fingerprint" is determined for a defined area.
By matching the fingerprint of the caller's signal with a
database of known fingerprints, the caller's geographic
location is identified to one of the surveyed areas.

[0039]   A handset-based technology may employ wireless
system signals, satellite signals, or a combination of wireless
system and satellite signals. Wireless communication devices
24 that use wireless system signals transmitted by base
stations serving wireless communication network 26, perform
algorithms such as Advanced Forward Link Trilateration (AFLT)
to determine current location. Wireless communication devices
24 that use satellite signals are furnished with a Global
Positioning System (GPS) receiver and make use of signals
received from multiple Global Positioning System (GPS)
satellites to determine current location. The current
location, ascertained using a handset-based technology, is then
communicated through wireless communication network 26 to PSAP
32.

[0040]   The network-based and handset-based location
determination technologies described above are an exemplary
representation of the possible techniques that may be utilized
to implement ALI system 36 within environment 20. The present
invention is not limited to the particular ALI system
implemented within an environment. Rather, the present
invention advantageously evaluates the accuracy of location
estimates provided by any current and future automatic location
identification (ALI) systems deployed within an environment.
Furthermore, the ALI systems need not be limited to ALI systems
that only locate wireless communication devices initiating
emergency calls. Rather, the present invention may evaluate
ALI systems adapted to locate wireless communication devices
initiating any type of call.

[0041]   FIG. 2 shows a flow chart of an automatic
location identification (ALI) evaluation process 38 in
accordance with the present invention. ALI evaluation process

38 may be initiated to evaluate the accuracy of ALI system 36
(FIG. 1) deployed within environment 20 (FIG. 1). ALI
evaluation process 38 begins with the execution of a validation
region identification subprocess 40, followed by the execution
of a sub-region classification subprocess 42, which is then
followed by a test point selection subprocess 44. Following
test point selection subprocess 44, a test call execution
subprocess 46, generally represented by dashed lines, is
executed. After test call execution subprocess 46, ALI
evaluation process 38 proceeds to the execution of an analysis
subprocess 48. Following analysis subprocess 48, ALI
evaluation subprocess 38 exits.

[0042]   In a preferred embodiment, validation region
identification subprocess 40, sub-region classification
subprocess 42, and test point selection subprocess 44, and
analysis subprocess 48 are largely carried out as automated
processes utilizing a computing system, described below. Test
call execution subprocess 46 may be carried out by utilizing an
empirical methodology, a predictive methodology or a hybrid
methodology. As such, test call execution subprocess 46 begins
with a query task 49. At query task 49, a determination is
made as to whether only empirical methodology is to be used.
When only empirical methodology is to be used, test call
execution subprocess 46 continues with the execution of an
empirical test call execution subprocess 50. Following the
execution of empirical test call execution subprocess 50, ALI
evaluation process 38 proceeds to analysis subprocess 48.
However, when there is a negative response to query task 49,
test call execution subprocess 46 advances to a query task 51.

[0043]   At query task 51, a determination is made as to
whether only predictive methodology is to be used. When only

predictive methodology is to be used, test call execution
subprocess 46 continues with the execution of a predictive test
call execution subprocess 52. Following the execution of
predictive test call execution subprocess 52, ALI evaluation
process 38 proceeds to analysis subprocess 48. However, when
there is a negative response to query task 51, test call
execution subprocess 46 advances to a task 54.

[0044]   At task 54, a combination of empirical and
predictive test call execution subprocesses 50 and 52,
respectively, is executed (discussed below). Following task
54, ALI evaluation process 38 proceeds to analysis subprocess
48. For clarity of understanding, the subprocesses of ALI
evaluation process 38 (i.e., validation region identification
subprocess 40, sub-region classification subprocess 42, test
point selection subprocess 44, empirical test call execution
subprocess 50, predictive test call execution subprocess 52,
and analysis subprocess 48) will be discussed separately
hereinbelow.

[0045]   FIG. 3 shows a block diagram of a computing
system 56 through which ALI evaluation process 38 (FIG. 2) is
executed. Computing system 56 includes a processor 58 on which
the methods according to the invention can be practiced.
Processor 58 is in communication with user I/O interface 60 and
memory 62.

[0046]   Processor 58 also includes a data reader (not
shown) for reading data from a storage device 63. The data in
storage device 63 includes, for example, a PSAP service area
database 64, a wireless carrier service area database 66, an RF
coverage area database 68, geographic and land use databases
70, a test scenario database 72, a emergency call history
database 74, an wireless call history database 76, and an RF

signal propagation model 78. The data reader may include a
hard disk drive internal or external to processor 58, a tape
drive, floppy disk drive, CD-ROM, or a combination thereof.
Storage device 63 may be, but is not limited to, a compact
disk, a personal computer memory card international association
(PCMCIA) card, a floppy disk, a server or multiple servers
accessible via the Internet, or a combination thereof.

[0047]   An input portion of user I/O interface 60 may
include, but is not limited to, input devices such as a
keyboard, mouse, trackball, joystick, touch sensitive tablet or
screen, or a combination thereof for entering data and commands
into processor 58. Likewise, an output portion of user I/O
interface 60 may include output devices utilizing any known
means for displaying textual, graphical, or video images from
processor 58. The components of computing system 56 discussed
above may be implemented utilizing several known off-the-shelf
components.

[0048]   Processor 58 is capable of executing some or all
of a number of software modules, for example, validation region
identification subprocess 40, sub-region classification
subprocess 42, test point selection subprocess 44, test call
execution subprocess 46, and analysis subprocess 48. Memory 62
is an addressable storage medium, readable by processor 58,
upon which information and executable code, such as ALI
evaluation process 38, is stored.

[0049]   In addition, memory 62 has stored therein a
validation region map 82 generated during the execution of
validation region identification subprocess 40 (FIG. 2), and a
populated validation region map 84 and a sub-region
classification database 86 generated during the execution of
sub-region classification subprocess 42 (FIG. 2). In addition,

memory 62 has stored therein a test point database 88 generated
through the execution of test point selection subprocess 44
(FIG. 2). Test point database 88 may be subdivided into a
preliminary set 90, a candidate set 92, and a final set 94 of
test points (discussed below). Memory 62 further has stored
therein a call record database 96 generated during the
execution of test call execution subprocess 46 (FIG. 2), a
simulated environment database 98 formed during the execution
of predictive test call execution subprocess 52 (FIG. 2), and a
report 100 created during the execution of analysis subprocess
48 (FIG. 2).

[0050]   Although memory 62 is described as having all of
the above elements stored therein, it should be understood that
any of items 82, 84, 86, 88, 90, 92, 94, 96, 98, and 100 may
only be temporarily stored in memory 62 until a subsequent
operation or subprocess is executed, discussed below. In
addition, although computing system 56 is described as
performing all of subprocesses 40, 42, 44, 46, and 48 of ALI
evaluation process 38, it should be readily understood that
processor 58 may be utilized to execute some or all of the
subprocesses that form ALI evaluation process 38 (FIG. 2).
Alternatively, different portions of process 38 may be
distributed over a plurality of computing systems. Other
elements and processes may be implemented in conjunction with
those described herein and additionally other processes
referencing similar sequences of operations can be employed.

[0051]   FIG. 4 shows a flow chart of validation region
identification subprocess 40 of ALI evaluation process 38 (FIG.
1). Validation region identification subprocess 40 is executed
to identify geographic boundaries of a region in environment 20
(FIG. 1) for which ALI system 36 (FIG. 1) is to be evaluated.

[0052]   Subprocess 40 begins with a task 102. At task
102, processor 58 accesses PSAP service area database 64 (FIG.
1) to obtain a map of a PSAP service area for which ALI
evaluation process 38 (FIG. 2) is to be performed. PSAP
service area database 64 includes a list and boundary database
of PSAPs. One such database 64 is, but is not limited to,
MapInfo® PSAP Pro™ E9-1-1, provided by MapInfo Corporation,
Troy, NY. MapInfo® PSAP Pro™ E9-1-1 provides accurate
boundaries based upon jurisdictional areas for PSAPs and
telephone exchanges, and includes water bodies and unpopulated
areas. Detailed information about each PSAP also includes the
10-digit emergency number. In addition, because rural areas
and some suburbs have no PSAP, the MapInfo® PSAP Pro™ E9-1-1
database also includes information on the local sheriff or
police departments who cover emergencies in these areas.

[0053]   Referring to FIG. 5 in connection with task 102,
FIG. 5 shows a diagram of a service area map 104 of PSAP 32
(FIG. 1). Service area map 104 delineates a geographic
boundary of a service area 106 of PSAP 32. Although not shown
herein for simplicity, service area map 104 may also include
county, or city boundaries, with clearly identified landmarks
(i.e., streets, roads, highways, bodies of water, building
landmarks, and so forth). Service area map 104 further
includes PSAP information 108 that identifies PSAP 32. PSAP
information 108 may include, but is not limited to, the agency
name of PSAP 32, the administrative phone number, mailing
address, address of the PSAP site, 10-digit emergency number,
latitude and longitude of PSAP 32, and so forth.

[0054]   Referring back to validation region
identification subprocess 40 (FIG. 4), following task 102, a
task 110 is performed. At task 110, processor 58 (FIG. 3)

defines a wireless service area of wireless communication
network 26 (FIG. 1) corresponding to PSAP service area 106.
More specifically, processor 58 accesses wireless carrier
service area database 66 (FIG. 3) to acquire a map of a
wireless service area that approximately overlaps PSAP service
area 106 (FIG. 5). Wireless carrier service area database 66
generally includes a list and boundary database of regions or
markets of wireless communication network 26, and may be
maintained by the service provider of wireless communication
network 26 (FIG. 1).

[0055]   Referring to FIG. 6 in connection with task 110,
FIG. 6 shows a diagram of a wireless service area map 112 of
wireless communication network 26 approximately corresponding
to PSAP service area 106 (FIG. 5). Wireless service area map
112 delineates a geographic boundary of a wireless service area
114, depicted by a dark perimeter border, of wireless
communication network 26. In other words, wireless service
area map 112 illustrates a geographical reach of a wireless
communication network 26.

[0056]   Wireless service area 114 may include two or
more regions or markets of network 26. By way of illustration,
wireless service area 114 may include a first market/region "X"
116, a second market/region "Y" 118, and a third market/region
"Z" 120. Wireless service area 114 may be based on
metropolitan services areas (MSAs) and rural service areas
(RSAs), each of which in turn may be based on county
boundaries. Thus, an MSA or an RSA may include several
counties. In contrast, PSAP service area 106 (FIG. 5) is not
typically based on city or county boundaries. Wireless service
area map 112 may also include wireless service area information
122 that identifies the market/regions, for example, first,

second, and third market/regions 116, 118, and 120, depicted
herein.

[0057]   Referring back to validation region
identification subprocess 40 (FIG. 4), following task 110, a
task 122 is performed. At task 122, processor 58 (FIG. 3)
locates RF coverage holes within wireless service area 114
(FIG. 6). More specifically, processor 58 accesses RF coverage
area database 68 (FIG. 1) that identifies RF coverage holes
within wireless service area 114. RF coverage area database 68
generally includes a list and boundary database of RF coverage
holes within wireless communication network 26 (FIG. 1). RF
coverage area database 68 may be generated by collating call
history data for wireless service area 114, by taking field
measurements of signal strength, and/or by utilizing a radio
propagation tool to predict signal strength within wireless
service area 114.

[0058]   Referring to FIG. 7 in connection with task 122,
FIG. 7 shows a diagram of an exemplary radio frequency (RF)
coverage area map 124 of wireless communication network 26
(FIG. 1). RF coverage area map 124 delineates a geographic
boundary of RF coverage holes 126 within wireless service area
114. RF coverage holes 126 are those sub-areas located within
wireless service area 114 of wireless communication network 26
(FIG. 1) in which the signal strength of RF communication
signals is predicted to be below the design threshold. RF
coverage holes are usually caused by physical obstructions such
as buildings, foliage, hills, tunnels, indoor parking garages,
and so forth.

[0059]   The Federal Communication Commission (FCC)
requires that a location determination of wireless
communication device 24 (FIG. 1) originating emergency call 22

(FIG. 1) need only be found if emergency call 22 can be completed. Emergency call 22 is not likely to be completed in locations of RF coverage holes 126. As such, ALI evaluation process 38 need not be performed in the geographic regions delineated by RF coverage holes 126.

[0060]   Referring back to validation region identification subprocess 40 (FIG. 4), in response to task 122, program control proceeds to a task 128. At task 128, processor 58 (FIG. 3) dissociates RF coverage holes 126 from wireless service area 114 (FIG. 6) to produce RF coverage area map 124 of an RF coverage area 129 (FIG. 7). This dissociation is graphically represented in RF coverage area map 124 by hash marks through RF coverage holes 126. Thus, the signal strength of RF communication signals within RF coverage area 129 is predicted to be greater than a predetermined design threshold set by the service provider of wireless communication network 26 (FIG. 1).

[0061]   Following task 128, subprocess 40 proceeds to a task 130. At task 130, processor 58 (FIG. 3) selects a unit area for further assessment to determine whether the unit area is common to each of PSAP service area map 104 (FIG. 5) and RF coverage area map 124 (FIG. 7).

[0062]   Referring to FIG. 8 in connection with task 130, FIG. 8 shows a diagram of an exemplary overlay map 132 that represents PSAP service area 106 (FIG. 5) overlaying RF coverage area 129 (FIG. 7). Overlay map 132 is subdivided into a plurality of exemplary unit areas 134, of which only a few are shown in an exploded view of overlay map 132. Unit areas 134 are the basic units that make up overlay map 132. Overlay map 132 simulates environment 20 (FIG. 1) in which emergency dispatch service, via PSAP 32 (FIG. 1), and wireless

communication service, via wireless communication network 26
(FIG. 1), are provided. In a preferred embodiment, each of
unit areas 134 may be, but is not limited to, the smallest area
of interest, i.e., location, in environment 20. That is, the
size of each of unit areas 134 may be selectable and adjustable
to best accommodate the level of detail provided within overlay
map 132.

[0063]   PSAP service area database 64 (FIG. 3), wireless
carrier service area database 66 (FIG. 3), and RF coverage area
database 68 (FIG. 3) are configured as spatial databases. A
spatial database contains geographical or "spatial" information
in a prescribed format. For example, data entries of PSAP
service area database 64 may include coordinates identifying
each of unit areas 134 and spatial information relevant to the
serving PSAP for the identified unit area 134. Similarly, data
entries of wireless carrier service area database 66 may
include the coordinates identifying each of unit areas 134 and
spatial information relevant to the wireless service area of
the service provider. Likewise, data entries of RF coverage
area database 68 may include the coordinates identifying each
of unit areas 134 and spatial information relevant to the
signal strength of RF communication signals within the
identified unit area 134. Accordingly, information pertaining
to unit areas 134, i.e., spatially-referenced data, stored in
each of databases 64, 66, and 68, may be referenced using
spatial query techniques.

[0064]   With regard to task 130 (FIG. 4) of process 40
(FIG. 4), one of unit areas 134 is selected. A query task 136
is performed in response to task 130. At query task 136,
processor 56 (FIG. 3) executes a spatial query to determine
whether the identified one of unit areas 134 is common to PSAP

service area 106, represented by PSAP service area map 104
(FIG. 5), and RF coverage area 129, represented by RF coverage
area map 124 (FIG. 7). Processor 56 accomplishes task 136 by
querying each of PSAP service area database 64 (FIG. 3),
wireless carrier service area database 66 (FIG. 3), and RF
coverage area database 68 (FIG. 3).

[0065]   When query task 136 determines that the
identified one of unit areas 134 is not common to both PSAP
service area 106 and RF coverage area 129, process 40 proceeds
to a task 138. At task 138, the identified one of unit areas
134 is ignored. As such, the identified one of unit areas 134
is removed from further consideration. However, when query
task 136 determines that the identified one of unit areas 134
is common to both PSAP service area 106 and RF coverage area
129, process 40 proceeds to a task 140.

[0066]   At task 140, processor 58 (FIG. 3) adds the
identified one of unit areas to a validation region map
(discussed below). Following either of tasks 138 and 140,
process 40 proceeds to a query task 142. At query task 142,
processor 58 determines whether there is another one of unit
areas 134 for which a determination is to be made as to whether
it is common to both PSAP service area 106 and RF coverage area
129. When there is another of unit areas 134, program control
loops back to selection task 130 to select the next one of unit
areas 134 (FIG. 8). However, when there are no more of unit
areas 134, validation region identification subprocess 40
exits.

[0067]   FIG. 9 shows a diagram of validation region map
82 compiled through the execution of validation region
identification subprocess 40 (FIG. 4). Validation region map
82 represents a validation region 144 in environment 20 (FIG.

1) for which the deployed ALI system 36 (FIG. 1) may be
evaluated. Validation region map 82 is bounded by the
geographic boundary of PSAP service area 106 and excludes RF
coverage holes 126 (represented by hash marks) located in
wireless service area 114 (FIG. 7). Validation region map 82
is represented graphically for clarity of illustration.
However, like databases 64, 66, and 68 (FIG. 3), validation
region map 82 may be a spatial database containing a
compilation of unit areas 134 that are common to both PSAP
service area 106 and RF coverage area 129, and may be stored in
memory 62 (FIG. 3).

[0068]   With reference momentarily back to ALI evaluation
process 38 (FIG. 2), following the execution of validation
region identification subprocess (FIG. 4), resulting in the
generation of validation region map 82 (FIG. 3), process 38
proceeds to sub-region classification subprocess 42.

[0069]   FIG. 10 shows a flow chart of sub-region
classification subprocess 42 of ALI evaluation process 38.
Sub-region classification subprocess 42 is executed to classify
sub-regions within validation region 144 (FIG. 9) that exhibit
particular test scenarios, or environments, in which emergency
calls 22 (FIG. 1) may occur.

[0070]   Referring momentarily to FIG. 11, FIG. 11 shows a
table of a partial listing of test scenario database 72 that
includes exemplary test scenarios 148 in which the performance
of ALI system 36 (FIG. 1) deployed in environment 20 (FIG. 1)
may be evaluated. Wireless communication devices 24 (FIG. 1)
operate in a wide range of environments and conditions. To
characterize the performance of ALI system 36 under a realistic
range of distinct service areas and environments, aspects such
as the type of terrain, presence of natural and man-made

structures, speed, location of wireless communication devices
24, and time of day are taken into account. Through the use of
test scenarios 148, the range of typical operating conditions
is condensed into a manageable number of test cases so that a
comprehensive evaluation of ALI system 36 may be performed.
Accordingly, test scenarios 148 represent unique calling
environments within validation region 144 (FIG. 9).

[0071]   Each of test scenarios 148, identified by a
reference number 150, includes a combination of an environment
152 and a condition 154. Test scenarios 148 are subdivided
into distinct classes 156. Classes 156 include rural,
suburban, urban, highway, and water. Further distinction
regarding type of terrain and foliage, indoor/outdoor location,
types of man-made structures, and speed are made within each of
classes 156.

[0072]   In a preferred embodiment, the test scenario
database 72 can be formed from a listing of test scenarios
provided in the CDG Test Plan Document for Location
Determination Technologies Evaluation, Section 5, © 2000 CDMA
Development Group. The CDG Test Plan Document provides
definitions and guidelines for test criteria and test scenarios
for all possible location determination technologies (i.e.
automatic location identification systems) used to meet the FCC
E-911 Phase II requirements for locating wireless communication
devices based on the TIA/EIA-95 and IS-2000 family of dual mode
(analog and digital) standard in both the cellular and the
personal communication system (PCS) communication bands. The
present invention makes use of the listing of test scenarios in
the CDG Test Plan for clarity and standardization of the
evaluation of ALI systems. However, the test scenarios are not
limited to those defined in the CDG Test Plan, but may

encompass other present and future test scenario classification systems.

[0073]   With reference back to FIG. 10, sub-region classification subprocess 42 begins with a task 158. At task 158, processor 58 (FIG. 3) accesses memory 62 (FIG. 3) to obtain validation region map 82 (FIG. 9) generated during the execution of validation region identification subprocess 40 (FIG. 4).

[0074]   In response to task 158, a task 160 is performed. Task 160 causes processor 58 to populate validation region map 82 with the geographic and land use features of validation region 144 (FIG. 9). In particular, processor 58 accesses geographic and land use databases 70 (FIG. 3) from storage device 63 (FIG. 3), and using spatial query techniques, may merge information regarding the type of terrain and presence of natural and man-made structures.

[0075]   Geographic and land use databases 70 encompass terrain elevation, land use land cover, and streets, highways, landmarks, and buildings databases provided, for example, by MapInfo® Corporation, Troy, New York. In addition, demographic information can be utilized to obtain information regarding population distribution within validation region 144. In an exemplary embodiment, the present invention may utilize the programming platform MapXtreme® produced by MapInfo® Corporation, Troy, New York. MapXtreme® is a Java-based Internet mapping server for broad deployment of spatial-analysis mapping applications. At task 160, geographic and land use databases 70 (FIG. 3) are queried, using spatial query techniques, to populate validation region map 82 (FIG. 9) with geographic and land use features of validation region 144.

[0076]   FIG. 12 shows a diagram of populated validation region map 84 stored in memory 62 (FIG. 3) in response to the execution of task 160 of subprocess 42. Populated validation region map 84 is represented graphically for clarity of illustration. However, like validation region map 82 (FIG. 9), populated validation region map 84 may be a spatial database. Populated validation region map 84, in the form of a spatial database, is a compilation of validation region map 82 and geographic and land use databases 70.

[0077]   Validation region map 84 is a highly simplified diagram of validation region 144 in which a number of geographical and man-made features are included. Some of the geographical and man-made features shown in populated validation region map 84 include, for example, rural, hilly, dense terrain areas 162, roads 164, suburban areas 166, buildings 168, and so forth. Those skilled in the art will recognize that the complexity of populated validation region map 84 is limited by the information contained within geographic and land use databases 70. Consequently, as databases 70 are updated with more detailed information, populated validation region map 84 can also be updated with the more detailed information.

[0078]   Referring back to sub-region classification subprocess 42 (FIG. 10) and with continued reference to populated validation region map 84 (FIG. 12), following task 160, a task 170 is performed. At task 170, processor 58 (FIG. 3) partitions populated validation region map 84 into sub-regions 172. Sub-regions 172, of which only a few are shown in an exploded partial view of populated validation region map 84, are the basic units that make up populated validation region map 84. Each of sub-regions 172 relates to the smallest area

of interest, i.e., location, in validation region 144 of
environment 20 (FIG. 1). Thus, sub-regions 172 may be as small
as ten square meters. Sub-regions 172 may be, but are not
necessarily, related in size and location coordinates to unit
areas 134 (FIG. 8).

[0079]   Following task 170, a task 174 is performed to
select a next one of sub-regions 172. Of course, during a
first iteration of task 174, the "next" one of sub-regions 172,
is a first sub-region 172.

[0080]   In response to selection task 174, processor 58
(FIG. 3) correlates the selected one of sub-regions 172 with
one of test scenarios 148 (FIG. 11). That is, processor 58
compares the environment and probable conditions of the
selected one of sub-regions 172, determined through the
execution of task 160, with environment 152 (FIG. 11) and
condition 154 (FIG. 11) defined for each of test scenarios 148
in test scenario database 72 (FIG. 11). Processor 58
determines which of test scenarios 148 the selected one of sub-
regions 172 most closely resembles and retains that information
in sub-region classification database 86 (FIG. 3) stored in
memory 62 (FIG. 3).

[0081]   FIG. 13 shows an exemplary table of a partial
listing of sub-region classification database 86 (FIG. 3) that
includes sub-regions 172 (FIG. 12) within populated validation
region map 84 (FIG. 12) correlated with particular test
scenarios 148. Sub-region classification database 86
identifies each of sub-regions 172 by sub-region identifiers
180. Each of sub-region identifiers 180 is associated with a
location description 182 and one or more test scenarios 148.
Although location description 182 is shown in terms of
instructions readily interpreted by an individual reading from

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database 86, it should be understood that location description
182 may be identified in terms of a latitude and longitude, or
other coordinates that describe a geographic boundary of a
particular one of sub-regions 172.

[0082]   As further shown in sub-region classification
database 86, sub-regions 172, identified by sub-region
identifiers 180, may be correlated with more than one of test
scenarios 148 from test scenario database 72 (FIG. 11). For
example, sub-regions 172, identified by sub-region identifiers
180, labeled "C" and "D", are associated with two test
scenarios 148, identified by reference numbers 150, labeled "R-
12" and "R-13". Referring momentarily to test scenario
database 72 (FIG. 11), test scenario 148 identified by
reference number 150 of "R-12", defines an environment 152 of
hilly terrain, clear view of sky and a condition 154 of inside
car, stationary. Test scenario 148 identified by reference
number 150 of "R-13", defines an environment 152 of hilly
terrain, clear view of sky and a condition 154 of inside car,
moving 30 miles per hour. Accordingly, although environment
152 is the same for each of "R-12" and "R-13" test scenarios
148, the "R-12" and "R-13" test scenarios 148 are both
associated with "C" and "D" sub-regions identifiers 180,
because each of the conditions 154 of "R-12" and "R-13" could
occur in those sub-regions 172.

[0083]   With reference back to sub-region classification
subprocess 42 (FIG. 10), following task 176, a query task 184
is performed. At query task 184, processor 58 (FIG. 3)
determines whether there is another one of sub-regions 172 with
which one or more of test scenarios 148 is to be correlated.
When there is another one of sub-regions 172, program control
loops back to task 174 to select the next one of sub-regions

172 and correlate the selected one of sub-regions 172 with one
or more test scenarios 148 (FIG. 11).

[0084]   However, when processor 58 determines that there
is not another of sub-regions 172, subprocess 42 exits. Thus,
following the execution of subprocess 42 sub-region
classification database 86, correlating sub-regions 172 of
populated validation region map 84 (FIG. 12) with test
scenarios 148, is generated.

[0085]   As discussed in connection with ALI evaluation
process 38 (FIG. 2), following the execution of sub-region
classification subprocess 42 (FIG. 10), resulting in the
generation of sub-region classification database 86 (FIG. 13),
program control proceeds to test point selection subprocess 44
(FIG. 3).

[0086]   FIG. 14 shows a flow chart of test point
selection subprocess 44 of ALI evaluation process 38 (FIG. 2).
Test point selection subprocess 44 is executed to choose test
points within validation region 144 (FIG. 12), exhibiting
calling environments represented by test scenarios 148 (FIG.
11), at which test calls (discussed below) may be performed to
evaluate the accuracy of ALI system (FIG. 1).

[0087]   Subprocess 44 begins with a task 186. At task
186, processor 58 (FIG. 3) selects a next one of test scenarios
148 (FIG. 11) from test scenario database. Of course, during a
first iteration of task 186, the "next" one of test scenarios
148, is a first test scenario 148.

[0088]   Following task 186, a task 188 is performed. At
task 188, processor 58 (FIG. 3) creates a preliminary database,
i.e. preliminary test point set 90, of preliminary test points
190 correlated with the selected one of test scenarios 148.
More specifically, processor 58 accesses sub-region

classification database 86 (FIG. 13) and identifies those sub-regions 172, identified by sub-region identifiers 180 (FIG. 13) that were associated with the selected one of test scenarios 148, identified by reference numbers 150 (FIG. 13). Accordingly, at task 188, preliminary test points 190 in the form of identified sub-regions 172 are retained in preliminary test point set 90.

[0089] By way of example, at task 186, a test scenario 148 identified by reference number 150, labeled "R-12" was selected. Accordingly, task 188 creates preliminary test point set 90 for reference number 150, labeled "R-12", of sub-regions 172 correlated with test scenario 148, "R-12", in sub-region classification database 86 (FIG. 13). Sub-regions 172 correlated with reference number 150 are labeled by sub-region identifiers 180 of "C" and "D".

[0090] Only two of sub-region identifiers 180 are shown in preliminary test point set 90 for simplicity of illustration. However, it should be apparent that there may be many more sub-regions 172 within validation region 144 that exhibit the selected one of test scenarios 148. Alternatively, there may be no sub-regions 172 within validation region 144 that exhibit the selected one of test scenarios 148. As such, preliminary test point set 90 for the selected one of test scenarios 148 may be a null set of preliminary test points 190.

[0091] Following task 188, a task 192 initiates a preliminary test point examination. More specifically, task 192 reviews each of preliminary test points 190 for the selected one of test scenarios 148 for accessibility and closeness of match to the selected one of test scenarios 148. Task 192 may be accomplished by performing a ground survey in which personnel may physically visit the locations within

environment 20 (FIG. 1) represented by each of preliminary test

points 190 to determine their practicality as a viable test

point 194. A ground survey may weed out those preliminary test

points 190 that are inappropriate due to database error,

physical inaccessibility, and human factor issues.

Alternatively, or in addition, processor 58 (FIG. 3) may rank

preliminary test points 190 in accordance with their

practicality as one of viable test points 194.

[0092]   In response to task 192, a task 196 records

viable test points 194 in candidate test point set 92 of test

point database 88 (FIG. 3). Since viable test points 194 are

selected from preliminary test point set 90 of preliminary test

points 190, the number of viable test points 194 can be no

greater than, and is likely less than, the number of

preliminary test points 190 in set 90.

[0093]   Following task 196, a task 198 chooses test

points 200 from viable test points 194 of candidate test point

set 92. Test points 200 identify those locations from which

test calls (discussed below) will be placed upon initiation of

test call execution subprocess 46 (discussed in further detail

below). Task 198 encompasses a number of processes for

choosing test points 200. These processes include a manual

selection process, a random selection process, a selection

process based on wireless emergency call history, a selection

process based on wireless call frequency history, or a

combination thereof.

[0094]   Manual selection entails the ground survey

discussed in connection with task 196 to determine viable test

points 194. Task 198 subsequently entails determining how many

of viable test points 194 for the selected one of test

scenarios 148 will be tested based upon selection criteria,

such as geographic dispersion of test points 200 within
validation region 144 (FIG. 9), closeness of match to the
selected one of test scenarios 148, and geometric dispersion of
precision (GDOP) issues. Manual selection enables an
individual to select a more localized test point, i.e., a
specific location within a boundary of one of sub-regions 172
correlated with the selected one of test scenarios 148.

[0095]   Automated random selection entails initiating a
random selection process to choose test points 200 from viable
test points 194 correlated with the selected one of test
scenarios 148. For example, random selection process code
assigns a number to each of viable test points 194, or to each
of a sub-set of points within boundaries defined by each of
viable test points 194. Random selection process code further
includes a pseudorandom number generator to choose viable test
points 194 to be test points 200.

[0096]   A selection process based on wireless emergency
call history entails accessing emergency call history database
74 (FIG. 3) within storage device 63 (FIG. 3). Emergency call
history database 74 may include a combination of emergency
calls made over all wireless communication networks maintained
by multiple wireless service providers within validation region
144 (FIG. 9). The selection process based on emergency call
history may then weight viable test points 194 according to the
frequency of wireless emergency calls originated at those
locations represented by viable test points 194. By weighting
viable test points 194, more test points 200 are selected in
sub-regions 172 exhibiting a greater frequency of wireless
emergency calls.

[0097]   A selection process based on wireless call
frequency history is similar to a selection process based on

emergency call history, with the exception that the selection
process based on wireless call frequency history takes into
account all calls carried out (emergency or otherwise) at those
locations represented by viable test points 194.

[0098]   Task 198 further entails recording test points
200 in final test point set 94 for storage in memory 62 (FIG.
3). Since test points 200 are selected from candidate test
point set 92 of viable test points 194, the number of test
points 200 may be no greater than, and is likely less than, the
number of viable test points 194 in set 92. In particular, the
CDG Test Plan Document specifies a predetermined number of
locations, i.e., test points 200, to be tested per test
scenario 148. Hence, the outcome of task 198 is to choose a
number of locations, i.e., test points 200, from viable test
point set 92 that is equivalent to this predetermined number of
locations.

[0099]   Following task 198, a query task 202 determines
if there is another one of test scenarios 148 (FIG. 11) for
which test points 200 are to be chosen. When there is another
one of test scenarios 148, program control loops back to task
186. Alternatively, when query task 202 determines that there
is not another one of test scenarios, test point selection
subprocess 44 exits having generated final test point set 94 of
test points 200 for each of test scenarios 148 representing
unique calling environments within validation region 144 (FIG.
9).

[0100]   Those skilled in the art will recognize that
there is a great variation in task execution in test point
selection subprocess 44. For example, tasks 188, 190, 198 may
be combined or reordered according to the code development of
test point selection subprocess 44 and the extensiveness of the

ground survey of test points. Furthermore, test point database 88 (FIG. 3) need not have separate databases of preliminary test point set 90, candidate test point set 92, and final test point set 94. Instead, test point database 88 may include a single set of test points ranked according to viability, such that subsequent subprocesses selects test points from the single set of test points according to their ranking.

[0101]   As discussed in connection with ALI evaluation process 38 (FIG. 2), following the execution of test point selection subprocess 44 (FIG. 14), resulting in the generation of final test point database 88 (FIG. 3) that includes test point set 94 of test points 200 (FIG. 14), program control proceeds to test call execution subprocess 46. Further as discussed, subprocess 46 may be executed using an empirical methodology, a predictive methodology, or a combination of empirical and predictive methodologies. The combination approach of task 54 (FIG. 2), for example, may utilize predictive test call execution subprocess 52 (FIG. 3) for test scenarios 148 (FIG. 11) in validation region 144 (FIG. 9) which lend themselves more easily to propagation modeling (flat terrain, light foliage, rural, etc.). Additionally, the combination approach of task 54 may utilize empirical test call execution 50 (FIG. 3) for test scenarios 148 for which propagation modeling may be more complex, such as urban areas, mountains, canyons, heavy foliage, etc.). Furthermore, empirical test call execution subprocess 50 may be performed in conjunction with predictive test call execution subprocess 52 at task 54 to validate the results obtained through predictive subprocess 52. For clarity, each of empirical and predictive test call execution subprocesses 50 and 52 are described hereinbelow.

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[0102]   FIG. 15 shows a flow chart of empirical test call execution subprocess 50 of ALI evaluation process 38 (FIG. 2). Empirical test call execution subprocess 50 calls for performing test calls from the actual locations, represented by test points 200 (FIG. 14), determining the actual coordinates, i.e., ground truth, of the locations, obtaining a location estimate, i.e., reported location, from ALI system 36 (FIG. 1), and comparing the reported location with the ground truth.

[0103]   Subprocess 50 begins with a task 204. At task 204, a next one of test scenarios 148 (FIG. 11) is selected from test point database 88 (FIG. 3). Subprocess 50 is only concerned with those unique calling environments represented by test scenarios 148 that are exhibited within validation region 144 (FIG. 9). As such, only those test scenarios 148 having test points 200 (FIG. 13) associated therewith in final test point set 94 (FIG. 13) of test point database 88 (FIG. 1) need be evaluated. In addition, during a first iteration of task 204, the "next" one of test scenarios 148, is a first test scenario 148.

[0104]   Following task 204, a task 206 is performed. At task 206, a next test point 200 is chosen from final test point set 94 associated with the selected one of test scenarios 148. Of course, during a first iteration of task 206, the "next" one of test points 200, is a first test point 200.

[0105]   In response to tasks 204 and 206, a task 208 determines a ground truth of the chosen one of test points 200. The ground truth may be the reference coordinates, expressed in latitude and longitude, of a test device, such as wireless communication device 24 (FIG. 1), being used to carry out empirical test call execution subprocess 50. Ground truth may be determined using differential global positioning satellite

(GPS) techniques, by performing a professional survey, or by using a reference point with known coordinates.

[0106]   The ground truth may be determined by using differential GPS when at least four satellites are "visible" to, i.e., detectable by, wireless communication device 24. Such a scenario is likely in rural areas of no or light foliage, suburban areas, some light and medium urban areas, and for highway scenarios. A professional survey may be performed to determine the ground truth if only three or less satellites are consistently "visible" to device 24 and a closest point at which at least four satellites are visible is at least one hundred meters away from test point 200.

[0107]   Ground truth may be determined from a reference point with known coordinates in all other scenarios. For example, for a selected one of test points 200, a reference point may be selected according to the criteria that at the reference point, at least four satellites are clearly "visible" using a differential GPS receiver, and the reference point is less than one hundred meters away from test point 200. A compass and a linear measuring device, e.g., rolling wheel, tape, range finder, etc., are used to determine the distance and angle between the reference point and test point 200.

[0108]   A task 210 is performed in conjunction with task 208. At task 210, a test call, simulating emergency call 22 (FIG. 1) is performed from test point 200. That is, an individual places the test call from the location in environment 20 (FIG. 1) corresponding to test point 200. The individual need not dial an emergency services number, such as "911". Rather, any number having a destination that is specifically designated for this application can be employed. While performing the test call, certain predetermined criteria

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are maintained for standardization across tests. This criteria
includes for example, performing test calls of fixed duration,
e.g., 30 sec, placement of wireless communication device 24
(FIG. 1) in a standard position next to a human head or phantom
head to simulate the effects of head blockage, and so forth.

[0109]   In response to task 210, a task 212 is performed.
At task 212, a location estimate, or reported location, is
obtained from ALI system 36 (FIG. 1). At this point in the
execution of subprocess 50, computing system 56 (FIG. 1) may be
serving as an answering point for receiving the test call and
receiving the reported location from ALI system 36. During the
duration of the test call, ALI system 36 (FIG. 1) deployed
within environment 20 (FIG. 1) will be collecting measurements
on signals received by ALI receivers at base stations 28 (FIG.
1).

[0110]   When ALI system 36 utilizes a network-based
technology, the collected measurements are processed by ALI
system 36 to obtain time difference of arrival (TDOA) data
and/or direction of arrival (DOA) data for angle of arrival
(AOA) algorithms. These, along with signal measurement quality
estimates, are used by ALI system 36 to obtain the reported
location of device 24 originating the test call.
Alternatively, when ALI system 36 utilizes a handset-based
technology, the collected measurements from multiple Global
Positioning System (GPS) satellites are processed by ALI system
36 to obtain the reported location.

[0111]   Following task 212, a task 214 is performed. At
task 214, a call record for the test call is produced.
Referring to FIG. 16 in connection with task 214, FIG. 16 shows
an diagram of call record database 96 stored in memory 62 (FIG.
3) that includes a plurality of call records 216 produced

through the execution of empirical test call execution
subprocess 50.

[0112]   Each of call records 216 includes reference
number 150, identifying one of test scenarios 148 (FIG. 11). A
suffix 218 is added to reference number 150 to indicate a
wireless service condition (i.e. "A" indicating a busy hour,
"B" indicating an off peak time, and "C" indicating night
time). Each of call records 216 further includes a trial
number 220, a ground truth 222, expressed in a latitude 224 and
a longitude 226, and a geolocation estimate, or reported
location 228. Reported location 228 may be expressed in a
latitude 230 and a longitude 232, and includes a time 234 that
reported location 228 was determined. Each of call records 216
also includes a time 236 that the test call was originated, and
a time 238 that reported location 228 was sent from ALI system
36 (FIG. 3) to the answering point, for example, processor 58
(FIG. 3).

[0113]   Call records 216 may also include additional
information for determining accuracy and latency of ALI system
36 (FIG. 3) as specified in the CDG Test Plan Document. The
additional information includes, for example, altitude, speed
(indicating movement of wireless communication device 24), and
heading (direction of movement) for both ground truth 222 and
reported location 228, and additional accuracy values for
handset-based ALI systems, such as number of visible
satellites, satellite identifiers, the ratio of received GPS
carrier signal power to the power spectral density of
background noise (C/N_0) values per visible satellite, and
horizontal dispersion of precision (HDOP) values.

[0114]   At task 214 (FIG. 15) of test call execution
subprocess 50, a first one of call records, designated first

call record 216', is produced at task 214 for a first test call
240 (see FIG. 1) performed in environment 20 (FIG. 1) at a
location corresponding to a first one of test points 200,
designated first test point 200' (see FIG. 12). Following task
214, a query task 242 is performed.

[0115]   At query task 242, a determination is made
whether to terminate first test call 240. The duration of all
test calls performed during the execution of empirical test
call execution subprocess 50 should desirably last a
predetermined duration, for example, thirty seconds. Query
task 242 monitors the elapsed duration of first test call 240
from time 236 of call origination to determine whether first
test call 240 is to be terminated. At query task 242, when the
elapsed duration of first test call 240 is greater than or
equal to the predetermined duration, first test call 240 is
terminated and subprocess 50 proceeds to a query task 244
(discussed below). Alternatively, at query task 242 when the
elapsed duration of first test call 240 is less than the
predetermined duration, first test call 240 continues and
subprocess 50 proceeds to a task 246.

[0116]   At task 246, a subsequent ground truth 222 is
determined, using the methods described above. In addition, a
task 248, is performed during the continuance of first test
call 240. At task 248, a subsequent reported location 228 is
obtained from ALI system 36 (FIG. 3).

[0117]   In response to task 246 and 248, a task 250 is
performed to include the subsequent ground truth 222 and
reported location 228 in call record database 96. Following
task 250, subprocess 50 loops back to query task 242 to again
determine whether first test call 240 is to be terminated.

[0118]   When wireless communication device 24 (FIG. 1) is
stationary, one or more subsequent measurements of reported
location 228 allows ALI system 36 to estimate a more accurate
location for reported location 228. Alternatively, when
wireless communication device 24 is moving, one or more
subsequent measurements of reported location 228 allows ALI
system 36 to track the movement of wireless communication
device 24. Referring momentarily to test scenario database
(FIG. 11), one of test scenarios 148, identified by reference
number 150 and labeled "R-13", includes condition 154 of
"inside car, 30 mph." Thus, reference number 150, "R-13",
represents a test scenario 148 in which wireless communication
device 24 is moving.

[0119]   With reference FIGs. 12 and 16, a second one of
call records 216, designated second call record 216", is
produced through the execution of subprocess 50 (FIG. 15) for a
second test call 252 (see FIG. 1) performed in environment 20
(FIG. 1) at an initial location corresponding to a second one
of test points 200, designated second test point 200" (see FIG.
12). Second test point 200" with suffixes "a", "b", and "c",
(200a", 200b", 200c") represent movement (i.e. subsequent
locations) at progressive instants in time of device 24 (FIG.
1). Accordingly, through the iteration of tasks 214, 242, 246,
248, and 250, second call record 216" includes multiple
latitudes 224 and longitudes 226 for ground truth 222 and
multiple latitudes 230, longitudes 232, and subsequent times
234 for the multiple estimates of reported location 228. That
is, a time 234 of "$T2b_E$" follows a first instant of time 234 of
"$T2a_E$", and a time 234 of "$T2c_e$" follows time 234 of "$T2b_E$".

[0120]   Referring back to query ask 242 of subprocess 50,
when the test call, such as first or second test calls 240 or

252 (FIG. 2) are terminated, subprocess proceeds to query task 244.

[0121] Query task 244 determines whether another test call is to be performed from the chosen one of test points 200, such as first or second test points 200' or 200" (FIG. 12). A comprehensive evaluation of ALI system 36 (FIG. 1) using empirical test call execution subprocess 50 is time consuming and costly due to the necessity of performing test calls from a number of locations corresponding to test points 200 (FIG. 14). Thus, it may be desirable to perform a fixed number of test calls, e.g. forty test calls, from the same location and determine ground truth 222 (FIG. 16) and reported location 228 (FIG. 16) for each of the test calls. As such, query task 244 determines whether another test call is to be performed from the location corresponding to the chosen one of test points 200. When another test call is to be performed, subprocess 50 loops back to task 210 to perform the test call and obtain reported location 228. However, at query task 244, when no further test calls are to be performed, subprocess 50 proceeds to a query task 254.

[0122] At query task 254, a determination is made whether another one of test points 200 is associated with the selected one of test scenarios 148 (FIG. 11). This is readily determined by consulting final set 94 (FIG. 14) of test points 200 (FIG. 14) in test point database 88 (FIG. 3). When there is another one of test points 200, subprocess 50 loops back to task 206 to choose the next one of test points 200 and subsequently perform test calls from the location in environment 20 (FIG. 1) corresponding to the next one of test points 200. However, at query task 254, when no further test

points 200 for the selected one of test scenarios 148 is
available, subprocess 50 proceeds to a query task 256.

[0123]   At query task 256, a determination is made
whether there is another one of test scenarios 148 exhibited
within environment 20 (FIG. 1). This is readily determined by
consulting test point database 88 (FIG. 3). When there is
another one of test scenarios 148, subprocess 50 loops back to
task 204 to select the next one of test scenarios 148, choose
test points 200 correlated with the next one of test scenarios
148, and perform calls from the locations in environment 20
(FIG. 1) corresponding the test points 200. However, at query
task 256, when no further test scenarios 148 are exhibited
within environment 20, empirical test call execution subprocess
50 exits having performed a comprehensive evaluation of ALI
system 36 (FIG. 1) deployed within validation region 144 (FIG.
9) and having generated call record database 96 (FIG. 16).

[0124]   FIG. 17 shows a flow chart of predictive test
call execution subprocess 52 of ALI evaluation process (FIG.
2). As discussed previously, a comprehensive evaluation of ALI
system 36 using an empirical approach, such as empirical test
call execution subprocess 50 (FIG. 15), is time consuming and
costly. Accordingly, in a preferred embodiment, predictive
test call execution subprocess 52 may be executed by processor
58 (FIG. 3) for some or all of test scenarios 148 (FIG. 11).

[0125]   Predictive test call execution subprocess 52
begins with a task 258. Task 258 involves the formation of a
simulated environment. Referring to FIG. 18 in connection with
task 258, FIG. 18 shows a diagram of a simulated environment
260 formed through the implementation of the predictive test
call execution subprocess 50 (FIG. 17) and stored in memory 62
(FIG. 3) as simulated environment database 98 (FIG. 3). Task

258 calls for obtaining populated validation region map 84
(FIG. 12) stored in memory 62 (FIG. 3) of computing system 56
(FIG. 3), and establishing RF signal propagation model 78 (FIG.
3) from storage device 63 (FIG. 3) within populated validation
region map 84 to form simulated environment 260. ALI system 26
is subsequently activated, through simulation, within simulated
environment 260.

[0126]   RF signal propagation model 78 represents the
propagation of RF communication signals through validation
region 144 (FIG. 6). More specifically, RF signal propagation
model 78 is implemented to predict the propagation of RF
communication signals from transmitter locations, such as from
base stations 28 (FIG. 1) and wireless communication devices 24
(FIG. 1), to characterize the behavior of signal loss as a
function of propagation distance, and to account for other
effects, such as terrain obstructions, sloping terrain, road
orientation, buildings, and so forth. RF signal propagation
model 78 may employ ray tracing techniques, image trees, and
such known to those skilled in the art. The information
produced by RF signal propagation model 78 includes predicted
propagation paths of RF signals transmitted from various
locations throughout wireless communication network 26 (FIG. 1)
and relative signal strength, i.e., power, of the RF signals
along the predicted propagation paths. The signal strength
calculations along the predicted propagation paths are
subsequently used by predictive test call execution subprocess
50 to simulate test calls within simulated environment 260.

[0127]   Following task 258, the subsequent tasks of
predictive test call execution subprocess 52 mimic the tasks of
empirical test call execution subprocess 50 (FIG. 15), but are
performed with respect to simulated environment 260.

[0128]   Thus, subprocess 52 continues with a task 262.
At task 262, a next one of test scenarios 148 (FIG. 11) is
selected from final set 94 (FIG. 14) of test point database 88
(FIG. 3). Like subprocess 50, subprocess 52 is only concerned
with those test scenarios 148 that are exhibited within
validation region 144 (FIG. 9). As such, only those unique
calling environments represented by test scenarios 148 having
test points 200 (FIG. 13) associated therewith in final test
point set 94 (FIG. 13) of test point database 88 (FIG. 1) need
be evaluated. In addition, during a first iteration of task
262, the "next" one of test scenarios 148, is a first test
scenario 148.

[0129]   Following task 262, a task 264 is performed. At
task 264, a next test point 200 (FIG. 14) is chosen from final
test point set 94 (FIG. 14) associated with the selected one of
test scenarios 148 (FIG. 11).

[0130]   In response to tasks 262 and 264, a task 266 is
performed. At task 266, processor 58 (FIG. 3) locates the next
one of test points 200, chosen at task 264, within simulated
environment 260. Referring momentarily to FIG. 18, a first one
of test points 200, designated first test point 200', is
located proximate one of buildings 168 in simulated environment
260.

[0131]   Following task 268, a task 270 is performed to
determine ground truth 222 (FIG. 16) within simulated
environment 260. Ground truth 222 is available within the
mapping databases that form populated validation region map 84
(FIG. 18) used to form simulated environment 260.

[0132]   Following task 268, a test call is simulated from
within simulated environment 260 from first test point 200'.
The predicted propagation paths from various locations within

populated validation region map 84 are known from RF signal propagation model 78. Thus, a test call 272 (FIG. 18) is initiated along the predicted propagation paths for reception at particular base stations 28 (FIG. 18) within simulated environment 260.

[0133] A task 274 is performed in response to task 270. At task 274, reported location 228 (FIG. 16) is obtained from ALI system 36 (FIG. 18) simulated within simulated environment 260. When ALI system 36 simulates a network-based technology, ALI system 36 estimates delay (angular) error for TDOA and AOA and the location error estimation (reported location 228) as a function of the delay (angle).

[0134] Following task 274, a task 276 causes processor 58 to produce a call record for the test call that includes ground truth 222 and reported location 228. The call record produced at task 276 is similar to those described in connection with task 214 (FIG. 15) of empirical test call execution subprocess 50, and may contain much the same information as do call records 216 of call record database 96 (FIG. 3).

[0135] Following task 276, a query task 278 is performed. Query task 278 is similar to query task 242 (FIG. 15) in that a determination is made whether to terminate simulated test call 272. When simulated test call 272 is terminated, subprocess 52 proceeds to a query task 280 (discussed below). However, when simulated test call 272 continues, subprocess 52 proceeds to tasks 282, 284, and 286.

[0136] Task 282 determines a subsequent ground truth 222. Task 284 obtains a subsequent reported location 228, and task 286 includes the subsequent ground truth 222 and reported location 228 in the call record, i.e., one of call records 216.

Tasks 282, 284, and 286 are similar to tasks 246, 248, and 250
(FIG. 15) of empirical test call execution subprocess 50 (FIG.
15) and will not be described in further detail herein.
Following task 286, subprocess 52 loops back to query task 278
to again determine whether simulated test call 272 is to be
terminated.

[0137]   When simulated test call 272 is terminated in
response to query task 278, query task 280 determines whether
another test call is to be simulated from the chosen one of
test points 200, such as first test point 200' (FIG. 18). When
query task 280 determines that another test call is to be
simulated, subprocess 52 loops back to task 270 to simulate the
test call in simulated environment 260 (FIG. 18) and obtain
reported location 228. However, at query task 280, when no
further test calls are to be simulated at first test point
200', subprocess 50 proceeds to a query task 288.

[0138]   At query task 288, a determination is made
whether another one of test points 200 is associated with the
selected one of test scenarios 148 (FIG. 11). This is readily
determined by consulting test point database 88 (FIG. 3). When
there is another one of test points 200, subprocess 52 loops
back to task 264 to choose the next one of test points 200 and
subsequently simulate test calls from locations in simulated
environment 260 (FIG. 18) corresponding to the next one of test
points 200. However, at query task 254, when no further test
points 200 for the selected one of test scenarios 148 is
available, subprocess 52 proceeds to a query task 290.

[0139]   At query task 290, a determination is made as to
whether there is another one of test scenarios 148 (FIG. 11)
exhibited within simulated environment 260 (FIG. 18). This is
again readily determined by consulting test point database 88

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(FIG. 3). When there is another one of test scenarios 148,
subprocess 52 loops back to task 262 to select the next one of
test scenarios 148, choose test points 200 correlated with the
next one of test scenarios 148, and simulated test calls from
the locations in simulated environment 260 (FIG. 18)
corresponding test points 200. However, at query task 290,
when no further test scenarios 148 are exhibited within
environment 20, predictive test call execution subprocess 52
exits having efficiently performed a comprehensive evaluation
of ALI system 36 (FIG. 1) through computer-based simulation,
and having generated call record database 96 (FIG. 16).

[0140]   Referring back to FIG. 2, following test call
execution subprocess 46, that includes either or both of
empirical test call execution subprocess 50 and predictive test
call execution subprocess 52, ALI evaluation process 38
proceeds to analysis subprocess 48. At analysis subprocess 48,
reported locations 228 (FIG. 16) of call record database 96
(FIG. 3) are compared with corresponding ground truths 222
(FIG. 16) within call record database 96, and report 100 (FIG.
3) is subsequently generated. Analysis subprocess 48 evaluates
the accuracy of ALI system 32 (FIG. 3). The accuracy may be a
measure that defines how close the reported locations 228 are
to the ground truths 222. Analysis subprocess 48 also
evaluates latency or the time needed from the instant of
origination of a test call from the wireless communication
device, time 236 (FIG. 16), to the instant reported location
228 is sent from ALI system 36, time 238 (FIG. 16). Other
information that may be gleaned through analysis subprocess 48
is capacity, i.e. the maximum number of independent
simultaneous location determinations ALI system 36 can sustain
for a given wireless communication network load, and

reliability, i.e., the total number of test calls that result in a reported location 228 relative to the total number of test calls.

[0141]   Analysis subprocess 48 may entail, for each test call, calculating the location error by determining the difference between reported location 228 and the corresponding ground truth 222. Analysis subprocess 48 can be performed using statistical techniques known to those skilled in the art. For example, the location error statistics can be plotted by generating a probability density function (pdf) and/or a cumulative distribution function (cdf). From the cumulative distribution function, the sixty-seventh percentile and the ninety-fifth percentile errors are determined, i.e., corresponding to the sixty-seventh percentile and the ninety-fifth percentile accuracy requirements specified in the FCC Phase II mandate for ALI systems. This error analysis may be repeated for each of test scenarios 148 tested.

[0142]   Finally, for a comprehensive analysis of validation region 144 as a whole, the results are linearly combined for all test scenarios 148. The results may be linearly combined by weighting the results of test scenarios uniformly. Other linear combination techniques are to weight the results based on emergency call history, wireless call history, predictions on probabilities of making calls from the environments represented by the different test scenarios, and so forth.

[0143]   In summary, the present invention teaches of a method and computing system for evaluating the accuracy of an automatic location identification system (ALI) deployed within a geographical region. The method and computing system evaluate an ALI system based on FCC accuracy and reliability

requirements specified by the FCC Phase II mandate for wireless
emergency call location. The present invention takes advantage
of automated methodologies for identifying a validation region,
classifying sub-regions within the validation region according
to test scenarios set forth in the CDG Test Plan Document for
Location Determination Technologies Evaluation, and selecting
test points within the validation region from which test calls
will be performed. In addition, the present invention teaches
of predictive test call execution methodology for simulating
test calls within an environment that simulates the actual
environment. The automated tools and methodologies are
utilized for repetitive tasks to minimize error and costs. In
addition, the methodology and computing system described herein
enable completion of comprehensive validations in a timely
manner with minimum need for specialized staff, and are
operable independent from the particular ALI technology
deployed. Furthermore, the methodology and computing system
can help to identify deployment upgrades in the ALI system due
to changes in the environment (addition of man-made structures
and land usage) and due to changes in the wireless
communication network configuration.

[0144]   Although the preferred embodiments of the
invention have been illustrated and described in detail, it
will be readily apparent to those skilled in the art that
various modifications may be made therein without departing
from the spirit of the invention or from the scope of the
appended claims. For example, there is a great variation in
the order in which many of the tasks described herein may be
performed.